SEARCH Atmospheric Element 1:

Retrospective Analysis of Arctic Clouds and Radiation from Surface and Satellite Measurements

YEAR 1 PROGRESS REPORT

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for funding under the SEARCH program

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Purpose

This report serves as summary of work done on Element 1 of the NOAA SEARCH project at the Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin-Madison (UW), NOAA Environmental Technology Lab, Boulder, CO, and CIRES/University of Colorado-Boulder.

Objectives

The objective of this element is to evaluate the degree to which historical and ongoing measurements can be used to answer SEARCH science questions and to aid in the evaluation of optimum locations for an expansion of the Arctic observing network (Element 3). The task is to perform a retrospective analysis of coincident surface measurements and satellite-derived quantities, comparing one to the other, and assessing the spatial and temporal variability in each parameter.

Our focus is on clouds and radiation but attention is also being given to surface properties, especially pertaining to recent trends in Arctic snow cover and sea ice that can induce a temperature-albedo feedback. Appropriate improvements in algorithms will be made, but the emphasis is on data analysis, not algorithm development. This work will also support the SEARCH Reanalysis Project (Element 7) that aims to exploit a variety of polar data sets and reanalysis products used in model studies.

The proposed research addresses the following SEARCH science questions:

- How can we characterize the composition, scales, and persistence of the recent complex of dramatic environmental changes in the Arctic system (termed Unaami in the SEARCH Science Plan)?
- Is Unaami consistent with natural variability, or are the climate changes it involves anthropogenic? How unusual are the Unaami changes in the context of instrumental and proxy records as well as model-based studies?
- What are the critical interactions among ocean, ice, land, and atmosphere as they relate to Unaami? Do albedo feedbacks from snow and sea ice extend the duration of melt season anomalies?
- How are global climate and Unaami coupled? How does warming associated with Unaami affect sea ice and can it initiate ice-albedo feedback?

Personnel

The lead scientist at NOAA/NESDIS and UW/CIMSS is Jeff Key. Xuanji Wang, a CIMSS postdoc performs most of the satellite data analysis. Our research involves the use of satellite data to estimate surface, cloud, and radiation properties over the Arctic, both on short and long time scales. Taneil Uttal, NOAA/ETL, and Robert Stone, CIRES/CU and NOAA/CMDL, are Co-Principal Investigators on this element of the NOAA SEARCH program. Their research involves surface-based cloud radar, radiation, and meteorological measurements.

Summary of Accomplishments

The originally proposed milestones for the first year were to (1) compile surface-based and satellite datasets in a form suitable for intercomparison and for use in regional climate models, and (2) validate satellite-derived surface, cloud, and radiative properties with surface data, primarily with data from the Barrow CMDL site. As will be demonstrated below, these milestones have been achieved. Our accomplishments for Element 1 include:

1. Satellite retrieval techniques for use with the AVHRR Polar Pathfinder (APP) dataset have been refined and validated with data from SHEBA and from Barrow, Alaska.
2. Surface, cloud, and radiation characteristics for 19 years of APP data have been estimated, and a data product has been made available to the public. An analysis of trends shows that the Arctic has been cooling at the surface during the winter, but warming at other times of the year. The surface albedo has decreased, particularly during the autumn months. Cloud amount has been decreasing during the winter but increasing in spring and summer. During summer, fall, and winter cloud forcing has tended toward increased cooling. This implies that if seasonal cloud amounts were not changing, surface warming would be even greater than that observed.
3. Trajectory analyses have been performed to produce Arctic station climatologies by season.
4. The snowmelt record of Barrow, Alaska (BRW) was updated and re-examined to substantiate a previously reported trend towards an earlier date of spring melt over Northern Alaska. Analyses corroborated earlier findings that diminished snowfall during winter and warmer spring temperatures are the cause. The onset and duration of the melt season over the western Arctic Ocean was found to correlate with the BRW snowmelt record, suggesting that the same dynamical and radiatively processes influence sea ice distribution and snow cover on land. Also, early snowmelt over southern land areas tends to accelerate melt of sea ice due to enhanced warm air advection.
5. A retrospective analysis of aerosol optical depth measurements derived from BRW sunphotometer data revealed distinctive spectral signatures in Arctic Haze and Asian Dust. These are two aerosol types that can perturb the radiometric structure of the Arctic atmosphere, and possibly influence cloud microphysical properties. Using model and empirical results to quantify the direct forcing on the surface radiation balance at BRW by Asian Dust, it was shown that a modest layer of dust has a cooling effect that exceeds the warming effect of a doubling of CO_2.
6. A 6-year record of cloud microphysics for NSA and the corresponding 6 year record of aerosol data were compiled.
7. The development of a cumulative tau technique for comparing surface and satellite cloud cloud properties was begun.
8. Comparisons have been undertaken between surface-derived cloud microphysics and satellite cloud microphysics for the (1) APP data set, the (2) MODIS-based cloud microphysics determined that the NASA/CERES team, a (3) VIIRS cloud typing algorithm that uses the standard MODIS cloud product, and (4) standard NOAA AVHRR cloud products.
9. Comparisons of multi-decadal APP-x satellite data for Barrow, Eureka, Alert and Tiksi were begun.

Details on these accomplishments are given in the next section.

Details of Accomplishments

Satellite Analyses

Satellite retrieval techniques for use with the AVHRR Polar Pathfinder (APP) dataset have been refined and validated. Retrieved parameters are surface temperature, surface albedo, cloud properties (particle phase, effective radius, optical depth, temperature, and pressure), and radiative fluxes under all-sky conditions. Data from the SHEBA experiment and two Antarctic meteorological stations have been used for validation.

Nineteen (19) years of APP data from the National Snow and Ice Data Center (NSIDC) have been acquired and processed. The twice-daily data cover the period 1989-1999 at a spatial resolution of 25 x 25 km^2, subsampled from the original 5 x 5 km^2 data. The area of coverage is shown in Figure 1. Monthly and seasonally averaged products were also created and archived. The extended APP dataset (APP-x) has been made available to the community for a variety of data comparisons and applications.

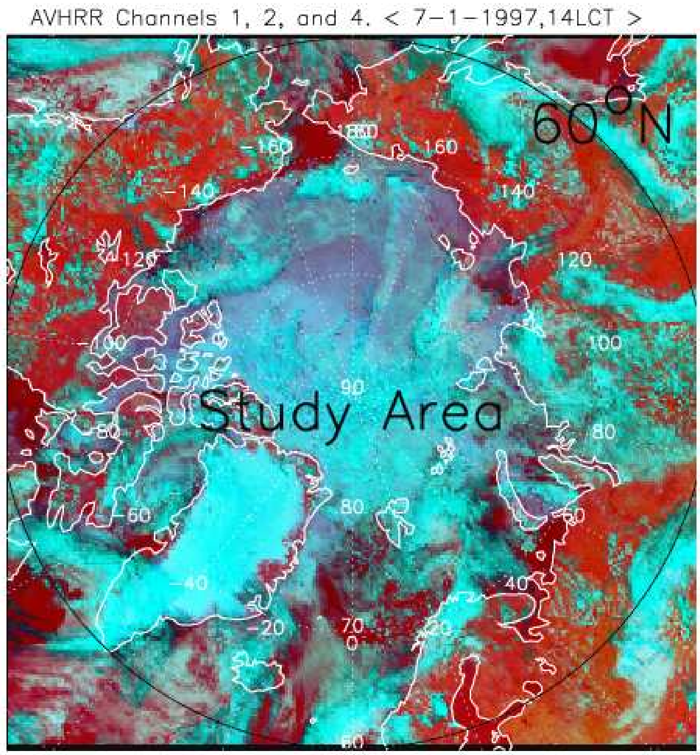


Fig. 1. The spatial coverage of the APP dataset during the period of 1982–1999. The image is a true color three channel (AVHRR channels 1, 2 and 4) composite.

Figure 2 shows the annual cycle of total cloud amount from the surface observations, the International Satellite Cloud Climatology Project (ISCCP) D2 product, the TOVS Path–P dataset, and the extended AVHRR Polar Pathfinder. The data in Figure 2 are averaged over the period 1982-1991. The surface-based climatology does not include clear sky ice crystal precipitation (ICP). ICP occurs in wintertime 20-50% of the time and may be optically thick enough to have a significant radiative effect. Overall, satellite derived products (APP-x) show good agreement with surface-based measurements, e.g., the biases between SHEBA ship measurements and APP-x dataset are 0.2 K in surface temperature, -0.05 (absolute) in surface broadband albedo, 9.8 Wm^{-2} in the downwelling shortwave radiation flux, and 2.1 Wm^{-2} in the downwelling longwave radiation flux.

Spatial and temporal characteristics of Arctic surface, cloud properties and radiative fluxes have been investigated. The daily APP-x composite data used here are centered on a local solar time of 1400. The area north of 60°N latitude is of primary interest. The daily results were averaged to obtain monthly, seasonal and yearly mean results. Figure 3 shows the annual cycles of cloud and radiation properties in the Arctic. Examples of the spatial distribution of cloud amount and cloud optical depth are given in Figure 4.

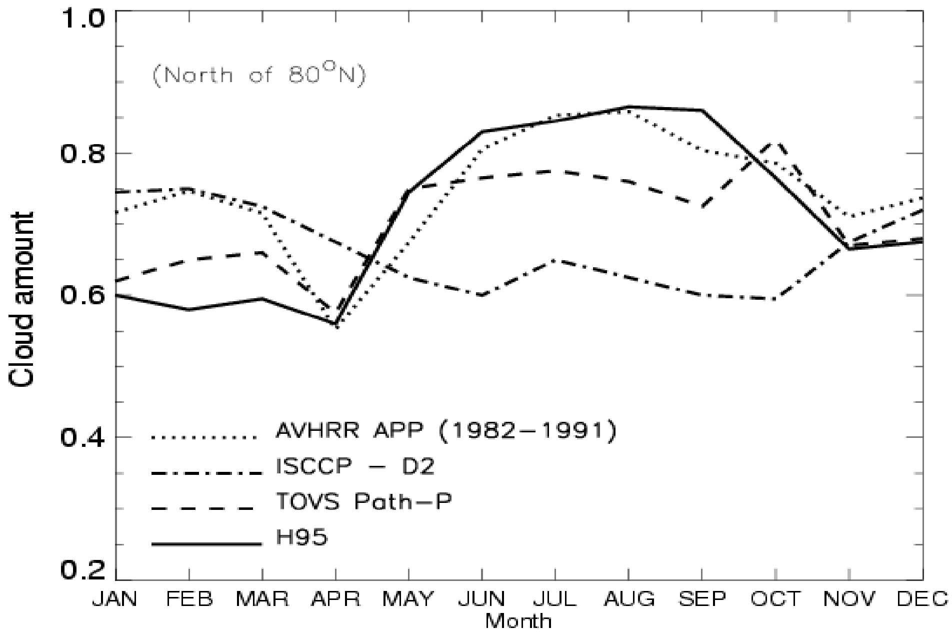


Fig. 2. The annual cycle of cloud amount from surface-based observations (H95) and satellite retrievals (ISCCP-D2, TOVS Path-P, and APP-x).

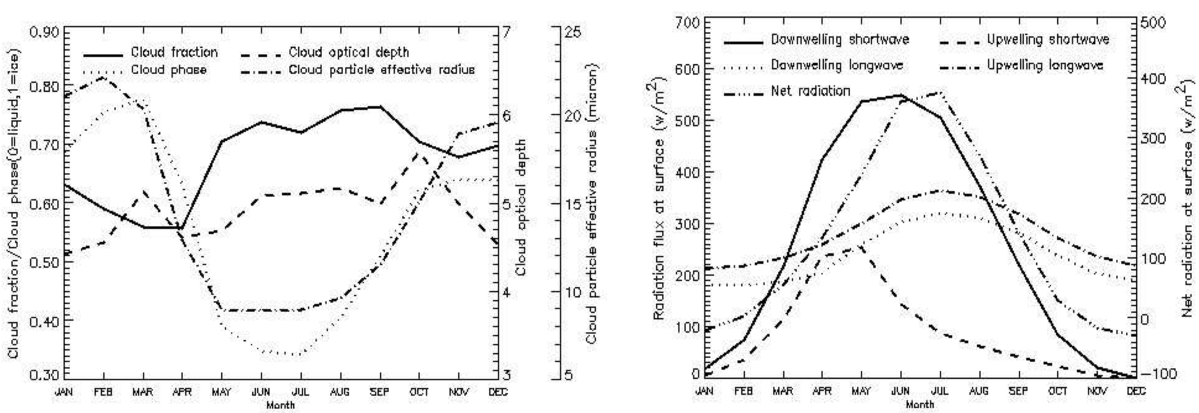


Fig. 3. Annual cycle of cloud fraction, cloud optical depth, cloud particle effective radius and cloud particle phase (left), and surface radiative fluxes (right) from APP-x.

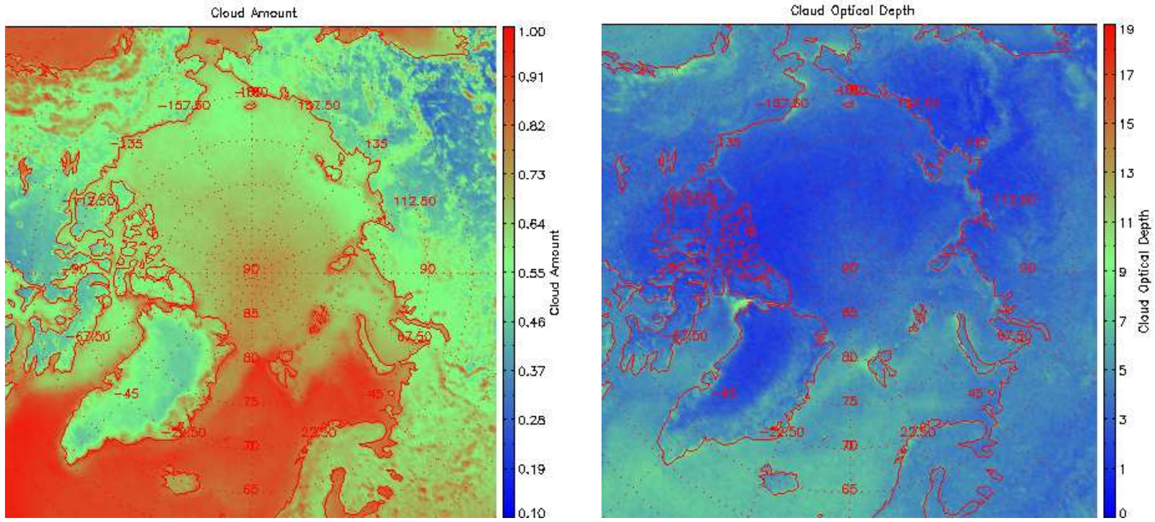


Fig. 4. The spatial distribution of cloud fraction (left) and cloud optical depth (right) in winter for the period 1982–1999.

In general, the Arctic surface temperature varies most over the landmasses, and least over the Arctic Ocean. Greenland is the coldest place in the Arctic all the year round. The Arctic is also one of the cloudiest regions on the earth, with an annual mean cloud coverage of about 70%. The visible cloud optical depth is about 5~6 on the annual average. Cloud top pressures are on average in the range 750-600 hPa except over Greenland where the average is approximately 600~450 hPa.

Trends in surface, cloud properties, and radiative fluxes, as well as their uncertainties and statistical significance, have been investigated. The ocean area north of 60º latitude has been cooling at the surface during the winter, but the Arctic overall has been warming at other times of the year. The wintertime surface temperature has decreased at the decadal rate of –0.35 degrees, but all other seasons have warming trends; the largest warming occurred in spring at the decadal rate of 0.12 degree. The wintertime decrease has also been observed in surface measurements and in the TOVS data record (A. Schweiger, pers. comm., 2003). The surface albedo has decreased, particularly during the autumn months. Cloud amount has been decreasing during the winter but increasing in spring and summer. The increase in spring cloud amount radiatively balances changes in surface temperature and albedo, but during summer, fall, and winter cloud forcing has tended toward increased cooling. This implies that if seasonal cloud amounts were not changing as they have been, surface warming would have been even greater.

Figure 5 shows the trends of cloud fraction and total precipitable water (from the NCEP/NCAR Reanalysis) in winter, spring, summer and autumn for the area north of 60ºN. Cloud fraction has decreased during the Arctic winter and increased in spring and summer. An example of the spatial variability in cloud amount trends is also shown in Figure 5.

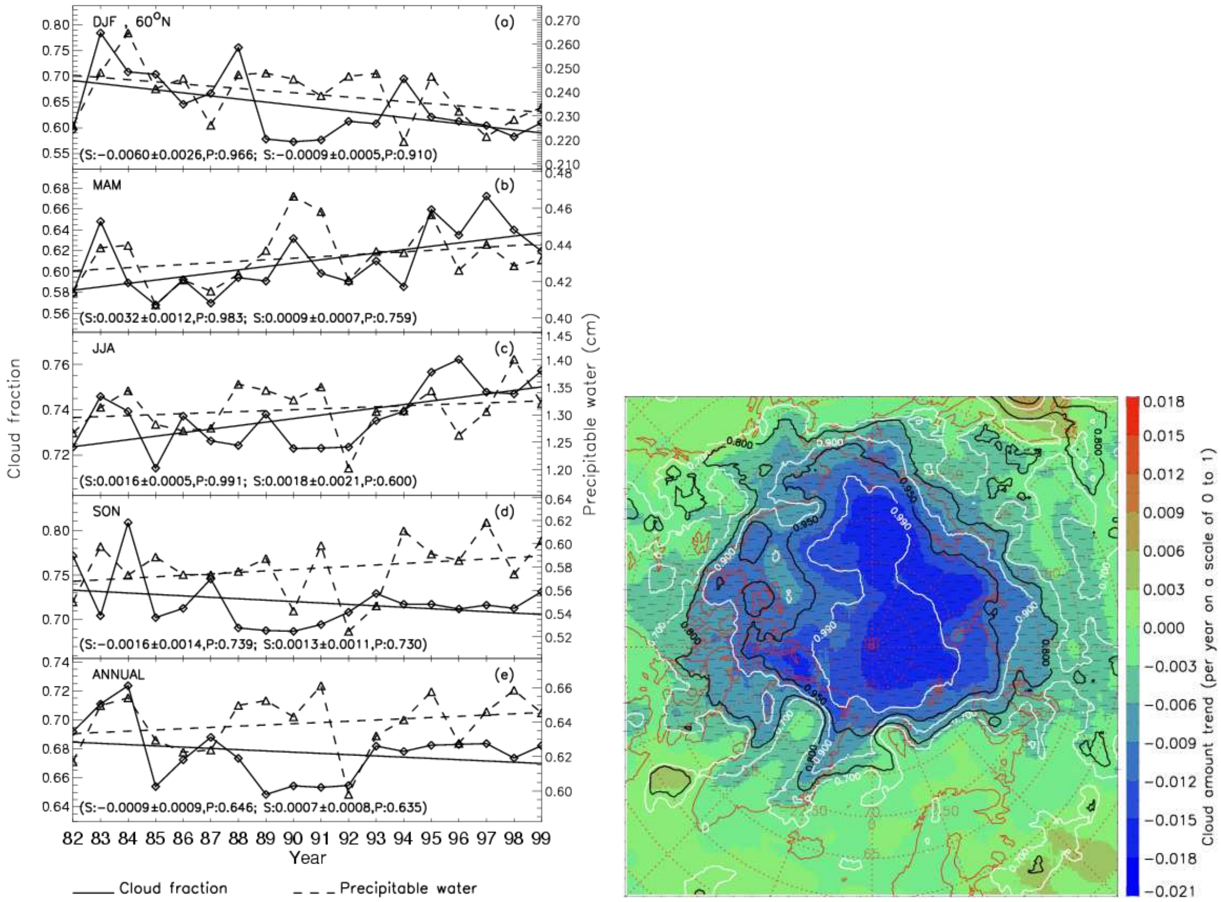


Fig. 5. **Left**: Time series and trends in cloud fraction and precipitable water in winter (DJF), spring (MAM), summer (JJA) and autumn (SON) over the area north of 60ºN. The numbers in parentheses are the slope of the trend with its uncertainty and F test confidence level, where S stands for slope per year and P for confidence level for that slope. The first group of S and P denotes the cloud fraction trend (solid line); the second group denotes the precipitable water (dashed line). **Right**: The spatial distribution of the trend in cloud fraction over the period of 1982 – 1999 in winter. The contours are the confidence levels; colors denote the trend magnitude, and areas with dash marks indicate decreasing trends.

Retrospective Analyses with Barrow Data

<u>Back Trajectory Analysis</u>

A trajectory analysis was performed to produce several Arctic station climatologies by season. An example for Alert, Canada, a site that is currently being enhanced as part of Element 3, is shown in Figure 6. Climatologies for four prospective Siberian sites were also generated (not shown). These are valuable for understanding flow patterns that influence cloud distribution and aerosol concentrations at these locations. At Alert, for instance, the flow at 1500 m is from central Greenland about 20% of the time during all seasons except summer. About 20% of the flow during all seasons is of local origin, northerly during winter/spring but southwesterly in summer and autumn. Long Range flow from Eurasia is common, especially during winter and spring. On this basis Arctic Haze probably is transported to Alert annually.

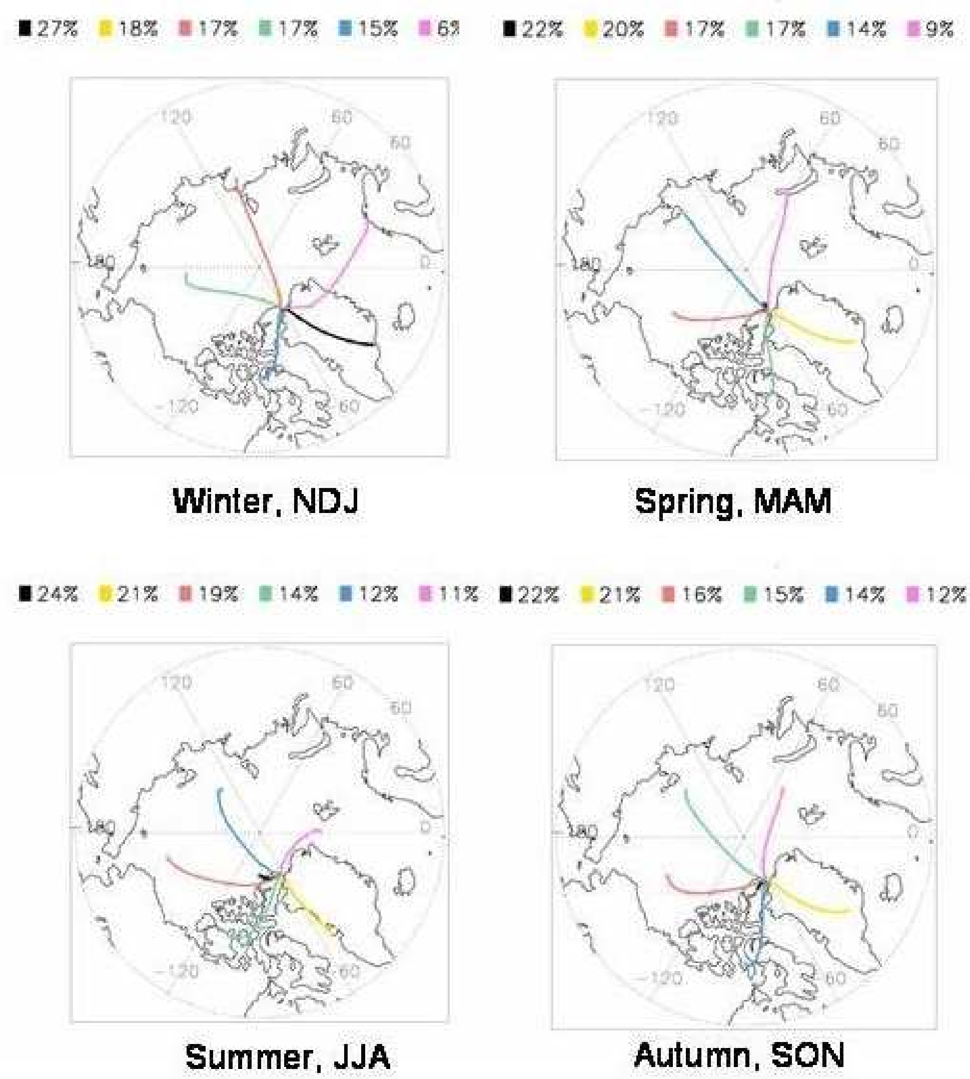


Fig. 6. Back trajectory climatology for Alert, Canada. The frequencies of six principal flow patterns are color coded as labeled. The arrival altitude is 1500 m, and the seasonal means are generated for all years, 1986-2002.

Correlated Trends in Sea Ice Extent and Snow Cover in the Western Arctic

Following on a previous study that documented a trend in the date when snow melts (melt date) at Barrow (BRW) in spring, an update was made and examined in the context of the entire western Arctic, including oceanic regions northwest of Barrow (details to appear in the *BAMS 2003 Climate Assessment - June 2004*). Although 1999, 2000, and 2001 were years of moderately late snowmelt at BRW, 2002 was the earliest on record. The 2003 melt was again early (Figure 7) further substantiating a trend towards an earlier spring melt in northern Alaska.

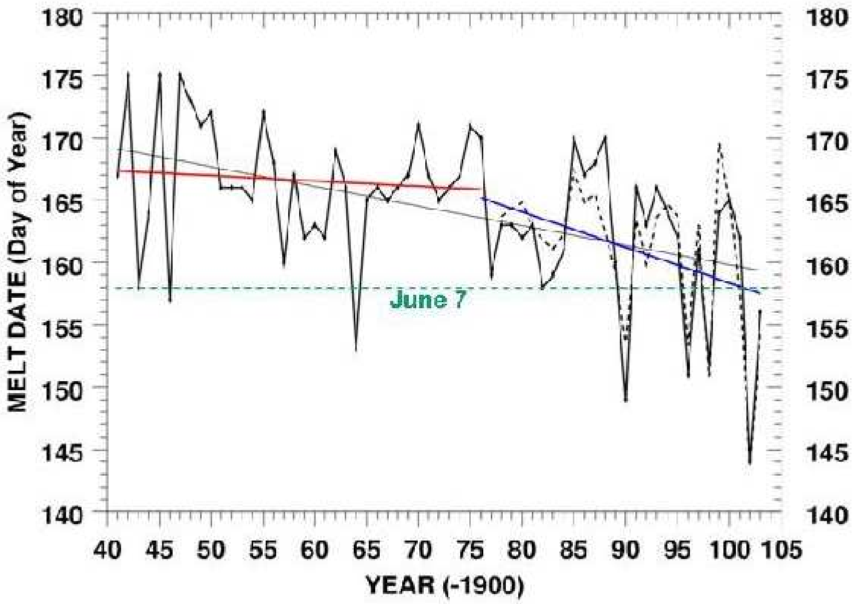


Fig. 7. Time series of snow melt dates constructed for the NOAA/CMDL Barrow Observatory. Three linear regressions are plotted: an overall fit for 1941-2003 (thin black line), one for all years prior to 1977 (red), and a third beginning in 1977 (blue). Results of an empirical model are also shown (dashed). The time series was compiled from direct snow depth observations, proxy estimates using daily temperature records, and beginning in 1986 on the basis of surface radiometric measurements (updated from Stone et al., 2002).

Since 1940 the spring melt at BRW has advanced by about 10 days (+/- 4.8 d, 95% confidence interval). Most of the advance occurred after 1976 when a major regime shift occurred in many climatic as well as biological indicators of climate change. Variations in the annual snow cycle of northern Alaska are attributable, in large part, to changes in atmospheric circulation that involve intensification of the Aleutian Low (AL) pressure center in conjunction with fluctuations of the Beaufort Sea Anticyclone (BSA). On this basis, an empirical model was developed to predict melt dates at BRW. Results are shown as a dashed curve in Figure 7. About 80% of the variance in melt dates at BRW can be explained by changes in snowfall during winter, and variations in springtime temperatures and cloudiness.

Using passive microwave data from polar orbiting satellites the onset of snowmelt on sea ice can be determined. Comparisons of time series of sea ice melt offshore Alaska with the timing of snowmelt across the North Slope of Alaska reveal a region of high correlation near the climatological center of the BSA. Analyses suggest that variations in the position and intensity of the BSA have far reaching effects on the annual accumulation and subsequent melt of snow and ice over a large region of the western Arctic.

There is general consensus that the overall decline in Arctic sea ice (since the late 1970s) is due to processes associated with dynamical changes in the atmosphere. Spring appears to be a critical transition period in the annual cycles of snow and sea ice. During years of early melt onset there tends to be a complete breakdown of the BSA during spring. In the absence of this High, the transport of warm, moist air into the Arctic is unrestricted. Using back trajectory analyses, it was found that the flow of southerly air masses into this region was a factor of three to four times more frequent during years of early melt than during years of late melt. This enhanced advection of warm air also adds moisture to the Arctic atmosphere, increasing cloudiness. Increased cloud cover is corroborated by independent analyses of the extended AVHRR Polar Pathfinder satellite data product. Prolonged effects of warm air advection augmented by thermal emissions from clouds (cloud radiative forcing) can modify the microphysical structure of the snow pack. It is thought that this "ripening" may precondition the snow such that the melt is accelerated during May/June when solar insolation reaches its annual peak. The depth of snow on sea ice prior to the onset of melt is also important because significant ice melt cannot occur until the insulating layer of snow melts first. It is suggested that reduced snowfall over the western Arctic Ocean in recent years may account, in part, for the decline in sea ice in that region.

Linkages to the disposition of the BSA (described above) suggest that regional scale climatology influences broad scale mechanisms and feedbacks that modulate snow cover and sea ice conditions in the western Arctic. Concerns arise as to whether or not recent trends resulting from these compounding positive feedbacks are manifestations of natural, low-frequency oscillations, or are anthropogenically forced. Will these mechanisms become self-propagating if the global temperature continues to rise? Answers to these questions have important ecological and cultural implications on a pan-Arctic scale.

Incursions and Impact of Asian Dust Over Northern Alaska

Using an assimilation of data collected at the CMDL Barrow Observatory (BRW), the direct effects of atmospheric aerosols on the surface radiation budget are being carefully monitored. In the past, the focus has been on "Arctic Haze" that is annually transported from Eurasia to BRW each spring. Analyses reveal incursions of Asian Dust as well. Spectral aerosol optical depth (AOD) measurements are used to differentiate dust from haze, whereby dust typically contains larger particles and is often of higher optical depth. Because polar atmospheres are generally very clean, even small increases in aerosol concentrations can perturb the radiometric structure of the atmosphere and thus the surface energy balance. Using an assimilation of data products available from BRW, the climate impact of different types of aerosols can be quantified as described below (details are given in the CMDL 2002-2003 Annual Report, 2004, in preparation).

During spring 2002, massive dust storms occurring in the Gobi Desert region of Mongolia lofted dust into the atmosphere that was transported eastward in a broad plume that reached the continental U.S. Some of this dust was blown over northern Alaska, passing over BRW. With the current complement of instrumentation at BRW it is now possible to track these events, monitor their physical properties, and derive or infer something about their optical and microphysical characteristics. For instance, the addition of a tracking sunphotometer system in 2000 has enabled quantification of AOD, while spectral signatures give relative particle size. In situ aerosol sampling at the surface can be used to investigate light scattering by aerosol particles from which fundamental optical properties can be derived, and particle analyses reveal chemical composition to fingerprint source regions. Dust layers are clearly visible in lidar profiles provided DOE ARM. Back trajectory analyses complement or substitute for chemical fingerprinting to determine source regions with some confidence. Finally, the suite of radiometers at the station yield an accurate time series of flux measurements from which the radiative forcing by aerosols can be estimated.

Results show that when dust is present in the Arctic atmosphere, the surface tends to cool, but to a lesser extent than at lower latitudes that are free of snow. Snow has a high albedo (reflectivity) that causes multiple reflections between the surface and aerosol layers, a process that absorbs a small amount of heat within the atmosphere. Highly absorbing particles would enhance this effect. Model results generally corroborate the empirical findings, giving credence to the use of surface radiation measurements for evaluating the climatic impact of aerosols in polar regions. In this particular case, for a modest optical depth in the visible spectrum, AOD (500 nm) = 0.15, this amounts to a negative forcing of about 5 W m^{-2} averaged over the diurnal cycle, a cooling effect that is greater than the warming estimated from a doubling of CO_2. Even though these are episodic events that occur mainly in late winter through spring, this is not an insignificant effect. Should the Arctic atmosphere become more turbid, projections of enhanced warming in the the Arctic may be overestimated due to this negative feedback. On the other hand, high concentrations of carbonaceous particles that absorb sunlight could lead to a positive feedback. Much more data and model simulations must be analyzed before we fully understand the climatic impacts of polar aerosols.

Extinction by aerosols in the atmosphere is greatest in the visible portion of the solar spectrum. Thus, solar irradiance reaching the surface diminishes measureably with increasing turbidity. It is straightforward to calculate the NET shortwave (SW) flux (NETSW = SWdown - SWup) at the surface and evaluate changes as a function of optical depth. When turbid conditions are compared with pristine periods, a measure of the direct radiative forcing by the intervening aerosol layers can be estimated. This quantity is referred to here as the Direct Aerosol Radiative Forcing (DARF). Similarly, radiative transfer theory can be used to calculate DARF. This was done to enable a comparison of model and empirical results, a first attempt at such a "closure experiment" for an Arctic location characterized by high surface albedo (82-84%) and low solar angles. MODTRAN 4, a well respected radiative transfer code developed by the Air Force, was used in this case.

Figure 8 compares the empirical and model results for three distinct solar zenith angles. These results illustrate the significant variation in DARF over a typical diurnal cycle for April at BRW. DARF is defined simply as the change in NETSW radiation per unit optical depth; i.e., the slope of each regression. Negative slopes indicate that the surface tends to cool when dust is present in the atmosphere above BRW during Spring. Table 1 compares the independent results of DARF estimated for each zenith angle.

Table 1. Direct Aerosol Radiative Forcing (DARF) at the surface for the April 2002 Dust episode at Barrow, Alaska. Units are Wm^{-2} $unitAOD^{-1}$

Zenith angle	81°	75°	62°
Observed	-16.1	-30.2	-37.8
Modeled	-14.4	-25.4	-30.9

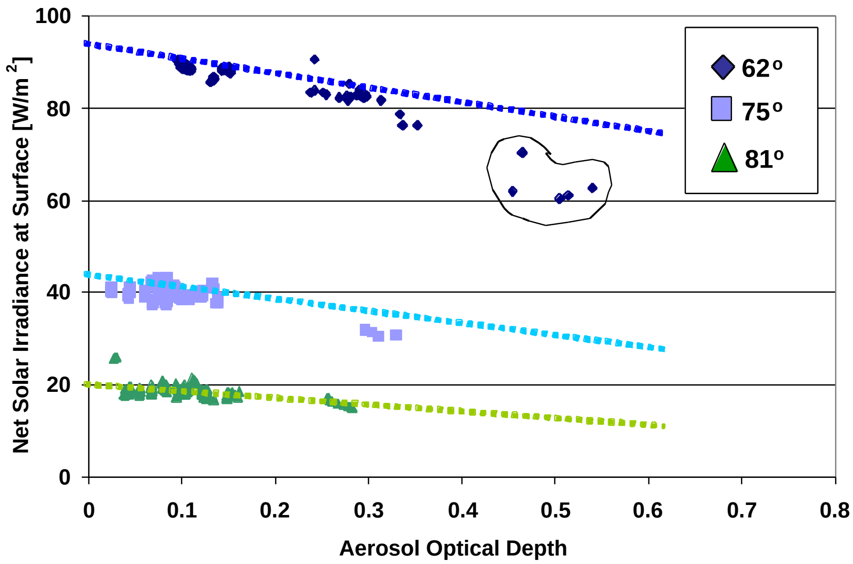


Fig. 8. Comparison of measured and simulated surface NET shortwave irradiance as a function of visible (500 nm) aerosol optical depth during an Asian Dust event at Barrow Observatory, April 2002. Symbols represent measurements and dashed lines give the results from MODTRAN 4 fitted using linear regression for selected zenith angles, as indicated. The enclosed (suspect) points were not used in the 62° analysis for purposes of computing DARF empirically. Results are summarized in Table 1.

Cloud and Surface Properties at Barrow

Annual time series of a number of cloud and surface properties have been examined for the 3 year period from 2000-2002 (Figure 9). The three year time series of surface temperature, total liquid path from a microwave radiometer, cloud fraction and total ice water path from cloud radar, and total aerosol concentration from a nephelometer show that all parameters have pronounced annual cycles. However, there will be considerable challenges in correlating these annual cycles. One issue is that aerosol concentrations at the surface are not necessarily representative of aerosol populations at cloud levels, therefore investigations of aerosol indirect effects will be difficult. A second issue is that the NSA radar had significant data outages during the spring/summers of 2001, 2002 and 2003. In the second year of this project, a number of methods will be investigated to make best use of these data, including monthly statistical sampling. The micropulse lidar at NSA might also allow for identification of the general structure of aerosol plumes in the atmosphere, which will in turn allow for some generalization of aerosol characteristics between the surface and cloud level.

Preliminary calculations have been made of monthly mean values of cloud properties to facilitate comparisons and annual trends. Figure 10 shows monthly statistics of radar-calculated ice water content for the month of January for 1999 through 2003.

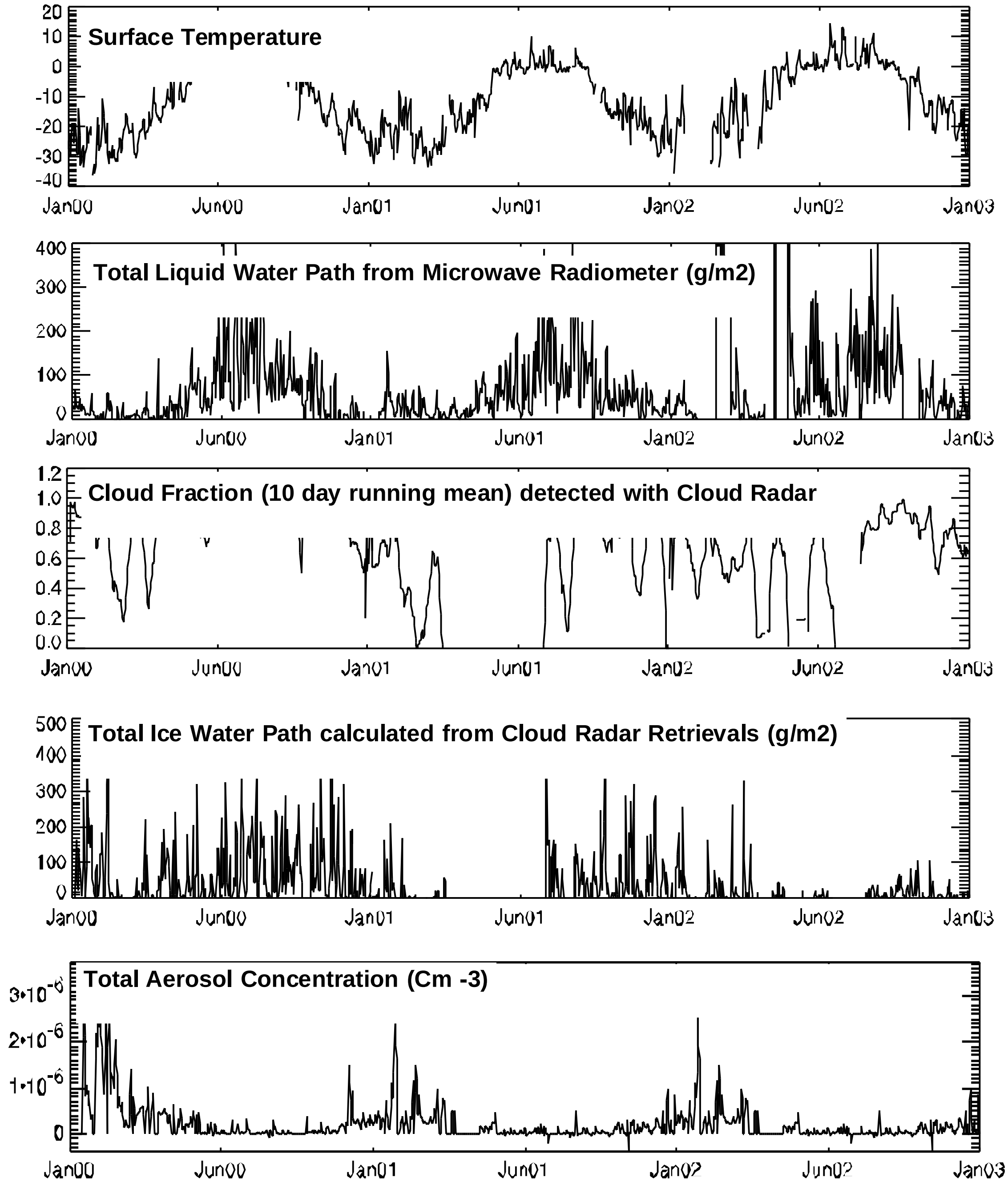


Fig. 9. Three year time series of surface temperature, total liquid path from (microwave radiometer), cloud fraction and total ice water path (from cloud radar), and total aerosol concentration (from nephelometer).

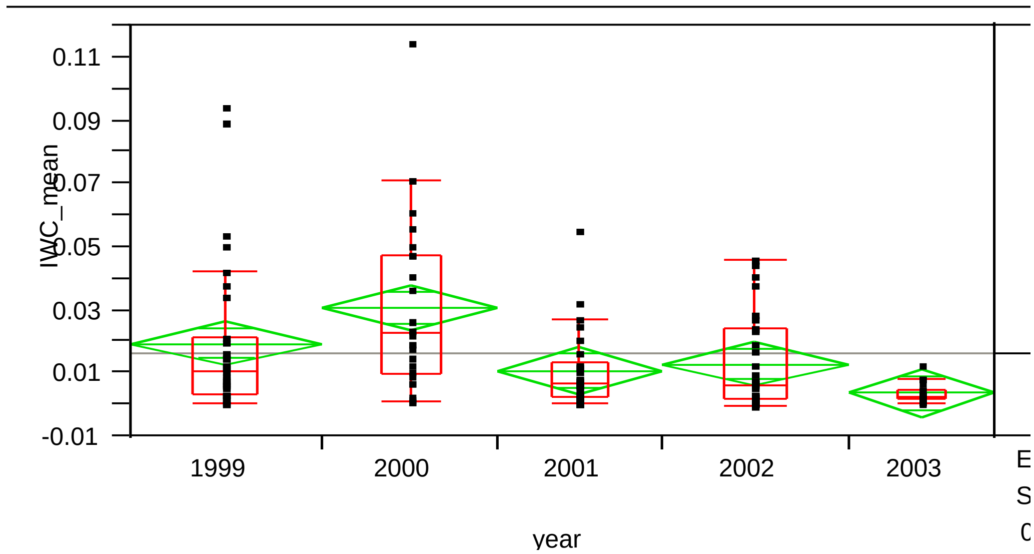


Fig. 10. Monthly statistics of radar calculated ice water contents for the month of January for 1999 through 2003.

Satellite times-have been extracted for Barrow, Alert, Eureka and Tiksi. These data sets will form the basis for studies of regional variations in cloud properties for the sites presently selected for existing (Barrow) and potential (Eureka, Alert, Tiksi) Atmospheric Observatories. Figure 11 shows one year (2000) of mean cloud hydrometeor size extracted from the APP-X dataset. While annual trends are similar, there are significant differences. For instance, Alert had smaller average cloud hydrometeor sizes, particularly in February and March.

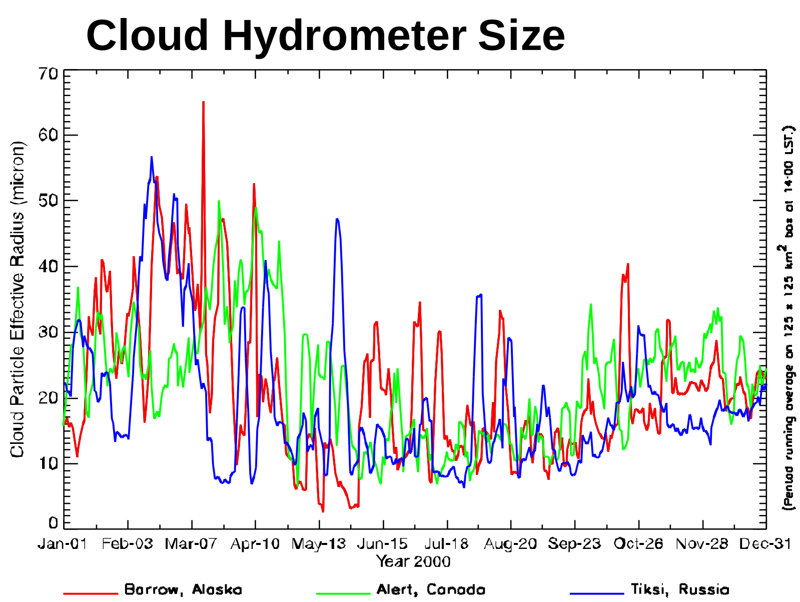


Fig. 11. One year (2000) of mean cloud hydrometeor size extracted from the APP-X satellite-based dataset.

Preliminary comparisons between CERES-team derivations of cloud optical depth for ice/water clouds and hydrometeor sizes are shown in Figure 12. Investigations of individual case studies are in progress to determine the reason for the wide scatter that exists. However, agreement on optical depths seem reasonable, especially for liquid clouds.

Comparisons have also been made for cloud classifications between the NSA surface radar-radiometer data with a VIIRS cloud typing algorithm that uses MODIS (day and night) data. The VIIRS algorithm was run for 67 single layer mixed phase clouds and 40 single layer ice clouds for 30 minute intervals centered on overpass times. This analysis showed that mixed phase clouds were identified correctly 90% of the time, and ice clouds were identified correctly 52% of the time (values provided Michael Pavolonis and Andrew Heidinger, SSEC/U of Wisconsin). The lower accuracy rate for ice clouds is hypothesized to be a function of higher transmission for liquid free clouds. As with the CERES-Team MODIS retrievals, discrepancies will be investigated with greater detail in the second year.

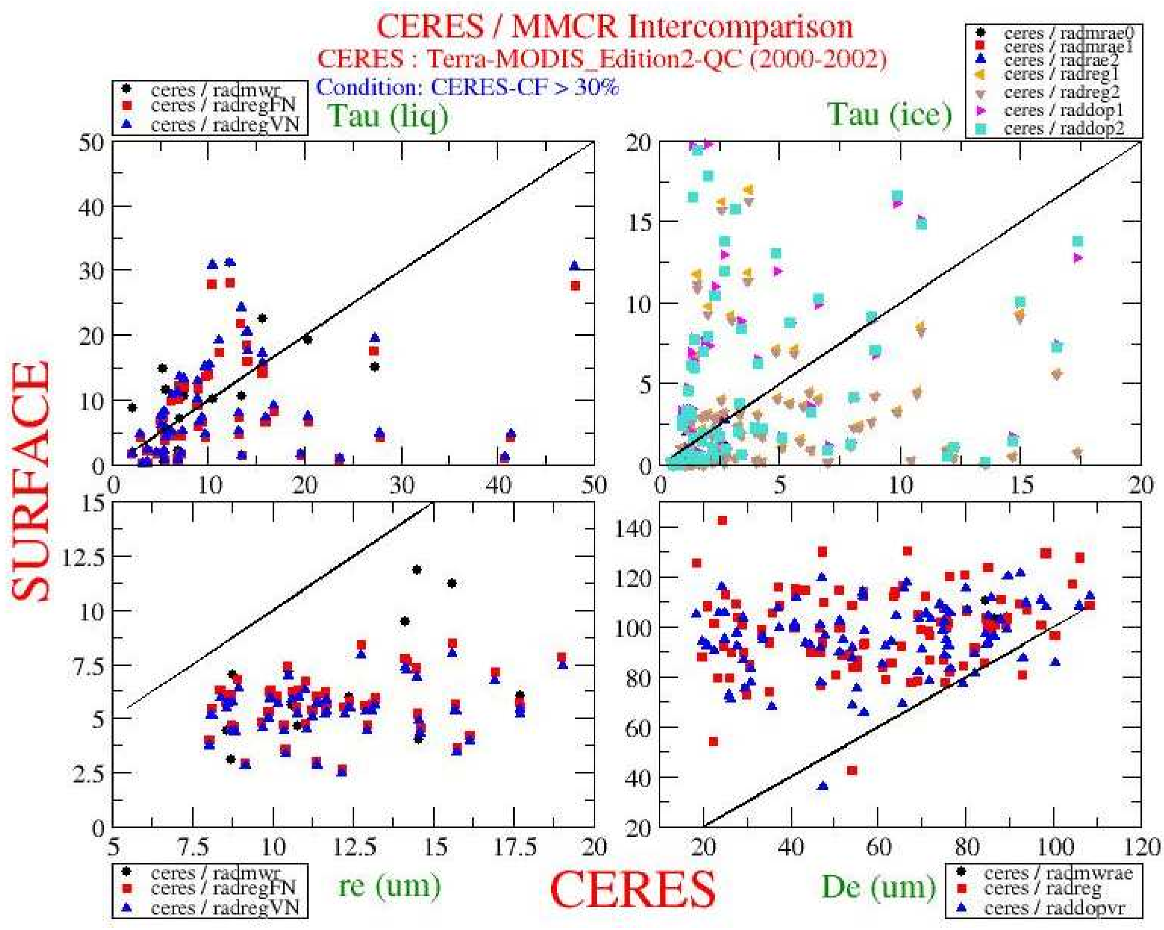
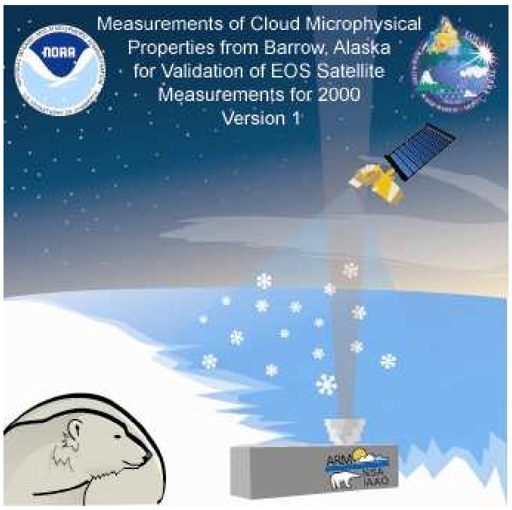
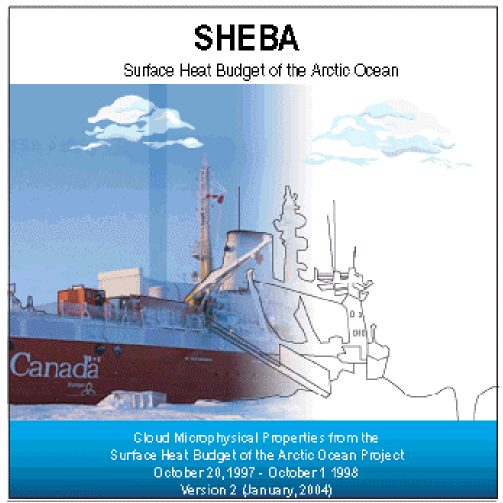


Fig. 12. Comparison between CERES-team derivations of cloud optical depth for ice/water clouds and hydrometeor sizes. (Figure courtesy of Sunny Sun-Mack, Douglas Spangenberg and Patrick Minnis, NASA/Langley.)

Data Products

A three year (2000, 2001, 2002) cloud microphysical dataset based on radar and radiometric data from the North Slope of Alaska, and for the SHEBA year (Nov 1997-Nov 1998), were released on CD and sent to an extensive mailing list of Arctic researchers. In addition, three more years of NSA data (1998, 1999, and 2003) have been processed, and it is anticipated that a second CD release will occur in FY2004. Data from 1998 at NSA has been "lost" to the ARM program since collection. Discovery of backup tapes at ETL for this period and subsequent processing is especially fortuitous as this period provides overlap with the SHEBA data sets.





Description of these data sets and products can also be viewed via the Web at:
http://www.etl.noaa.gov/arctic (see data links on left bar).

The APP-x dataset, consisting of retrieved surface properties, cloud properties and radiative fluxes for the area north of 60°N, was produced. Parameters are available on twice daily and monthly mean time scales. The data and read routines are available to the public at http://stratus.ssec.wisc.edu.

Publications

Journal Papers

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Liu, Y., J. Key, R. Frey, S. Ackerman, and W.P. Menzel, 2004, Nighttime polar cloud detection with MODIS, *J. Appl. Meteorol*., submitted (January 2004).

Shupe, M.D., and J.M. Intrieri, 2004: Cloud radiative forcing of the Arctic surface: The influence of cloud properties, surface albedo, and solar zenith angle. *J. Climate*, **17**, 616-628.

Wang, X. and J. Key, 2003, Recent trends in Arctic surface, cloud, and radiation properties from space, *Science*, 299(5613), 1725-1728.

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Zuidema, P., B. Baker, Y. Han, J. Intrieri, J. Key, P. Lawson, S. Matrosov, M. Shupe, R. Stone, T. Uttal: The Characterization and Radiative Impact of Springtime Mixed-Phase Cloudy Boundary Layer observed during SHEBA, *J. Atmos. Sciences*, submitted.

Conference Papers

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Plans

Our plans for the second and third project years are to focus on data analysis, including spatial and temporal variability, trends, and relationships to the AO and North Atlantic Oscillation (NAO). Climate indices will be explored. Interaction with investigators of the other proposed elements will increase during the second year and continue through the third year; e.g., datasets designed for assimilation in regional models will be compiled and delivered.

Because a number of different satellite groups are comparing different algorithms and sensors for cloud retrievals with the NSA ground data sets, a small 2-day collaboration meeting is being considered for the purpose of comparing results and standardizing comparison data sets as much as possible. Travel costs will be minimized by having the meeting at University of Wisconsin.

Funding

Year 1 funding for this project was $56,100 to NESDIS/CIMSS (Key), $54,000 to ETL (Uttal), and $86,000 to CIRES/CMDL (Stone). These amounts were a reduction in the proposed amounts. Nevertheless, the requested funding level for year 2 is the same as that for year 1, i.e., $56,100 to NESDIS/CIMSS (Key), $54,000 to ETL (Uttal), and $86,000 to CIRES/CMDL (Stone).